value of results obtained under circumstances of due precaution is pointed out by their success.

The position of the lines on the land portion of the map is derived from 120 determinations in various parts of Europe, Africa, and America, between the years 1834 and 1839, of which about the half are now first communicated.

The series of Messrs. Dunlop and Sulivan contain also observations of the magnetic intensity made at sea; Mr. Dunlop's by the method of horizontal vibrations, and Lieut. Sulivan's by the instrument and method devised by Mr. Fox. The degree of precision which may be obtained by experiments thus conducted, is shown by the comparison of these observations with each other, and with the isodynamic lines previously derived from observations made on land.

The first section of this paper concludes with discussions on the relative positions of the lines of least intensity and of no dip, and of the secular change which the latter line has undergone in the ten years preceding 1837.

In the second section, the observations of Mr. Dunlop are combined with recent observations on the coasts of Australia, by Captains Fitz Roy, Bethune, and Wickham, of the Royal Navy, to furnish a first approximation to the position and direction of the isodynamic lines over that portion of the Indian ocean which is comprised between the meridian of the Cape of Good Hope and New South Wales.

A paper was also in part read, entitled "Experimental Researches in Electricity, seventeenth series." By Michael Faraday, Esq. D.C.L., F.R.S., &c., On the source of power in the Voltaic Pile.

March 26, 1840.

The MARQUIS of NORTHAMPTON, President, in the Chair.

The reading of a paper, entitled "Researches in Electricity, Seventeenth Series: on the source of power in the Voltaic Pile." By Michael Faraday, Esq., D.C.L., F.R.S., &c., was resumed and concluded.

In this series, the author continues his experimental investigation of the origin of electric force in the voltaic pile. Having found abundant reason, in the experiments already described, to believe that the electricity of the pile has its origin in the chemical force of the acting bodies, he proceeds to examine how the circumstances which can affect the affinity of substances for each other, influence their power of roducing electric currents. First, with relation to *heat*:—circuits were made of a single metal and a single fluid, and these were examined with a view to ascertain whether, by applying

heat at one of the junctions, only thermo-currents can be produced. Some peculiar effects of heat are noticed and explained; and several very necessary precautions in conducting these experiments are pointed out; and it is found, when these are taken, that heat has a decided and distinct effect over the chemical affinities of the parts of a circuit subjected to its power, and a corresponding influence on the electric current produced. This proceeds to such an extent, that, in some cases, either of two metals can be made positive or negative with respect to the other in the same fluid, solely by virtue of this power of heat.

The effect of *dilution* is then examined. For this purpose, only one metal and one fluid are used in a circuit; but the fluid is rendered more dilute at one point of contact than at the other. It was ascertained that such dilution produces little or no effect with metals which are not acted on by the electrolyte employed; and the precautions requisite as to other points are then stated. But when these are observed, still dilution is found to have a most powerful influence on the results; and, as the author believes, solely on account of its influence on the active chemical affinity. Thus copper in dilute nitric acid is positive with respect to copper in strong nitric acid; and the same is the case with lead, silver, and other metals. It is not that the piece in the weakest acid is always positive with respect to that in the stronger acid; for, in the first place, some very curious cases are given, in which a piece of metal in acid of a certain strength is *positive* with respect to a piece of the same metal in acid, either stronger or weaker; and, in the next place, other cases are stated in which the piece in the medium acid is *negative* with respect to the other piece in either stronger or weaker acid. The effect of dilution in nitric acid is such, that when certain different metals are compared together, either can, at pleasure, be made positive or negative with respect to the other; thus, of the five metals, silver, copper, iron, lead, and tin, any one of them can be made either positive or negative with respect to any other; with the sole exception of silver, which is always positive with respect to copper. The inconsistency of these results with any theory of contact electromotive force is then strongly insisted on by the author.

The next division of the paper treats of the order of the metallic elements of voltaic circuits when different electrolytes are used. It is usual to say, that metals are positive or negative with respect to each other in a certain order; but Davy, and afterwards De la Rive, showed that, in certain cases, this order is inverted. The author, by using ten metals, and seven different exciting electrolytic solutions, shows that in no two solutions is the order the same; but that changes of the most extreme kind occur in exact conformity with the changes in chemical action, which the use of the different solutions occasions.

The next division of the paper considers the very numerous cases in which voltaic circuits, often such as are able to effect decomposition, are produced without any metallic contact, and by virtue of

chemical action alone; contrasting them with the numerous cases given in the previous series, where contact *without* chemical action, whether it be the contact of metal with metal, or with chemically inactive electrolytes, can produce no voltaic current.

The author then considers the sufficiency of chemical action to account for all the phenomena of the pile. He shows that chemical action does actually evolve electricity; that according as chemical action diminishes or ceases, so the electrical current diminishes or ceases also; that where the chemical action changes from side to side, the direction of the current likewise changes with it; that where no chemical action occurs, no current is produced, but that a current occurs the moment chemical action commences; and that when the chemical action which has, or could have produced a current, is, as it were, reversed or undone, the current is reversed or undone likewise; that is, it occurs in the opposite direction, in exact correspondence with the direction taken by the transferred anions and cathions. The accordance of the chemical theory of excitation with these phenomena is considered by the author as of the strictest kind.

The phenomena of thermo-electricity are considered by some philosophers as affording proofs of the efficacy of mere metallic contact in exciting an electric current. The author proceeds, therefore, to examine these phenomena in relation to such an action, and arrives at the conclusion, that they, in fact, disprove the existence of such a power. In thermo-electricity, the metals have an order which is so different from that belonging to them in any electrolyte, that it appears impossible to consider their succession, in any case, as due to any mutual effect of the metals on each other, common to both modes of excitation. Thus, in the thermo-circuit, the electric current is, at the hot place, from silver to antimony, and from bismuth to silver; but in a voltaic series, including dilute sulphuric or nitric acids, or strong nitric acid, or solution of potash, the electric current is from silver to both antimony and bismuth; whilst if the yellow sulphuret of potash be used, it is from both antimony and bismuth to silver; or if the hydro-sulphuret of potash be used, it is from bismuth to silver, and from silver to antimony; and, finally, if strong muriatic acid be used, it is precisely the reverse, that is, from antimony to silver, and from silver to bismuth. The inconsistency of these results with the contact theory is then insisted on and farther developed.

The last section of this series is on the improbability of there existing any such force as the assumed contact force. The author contends that it is against all natural analogy and probability that two particles which, being placed in contact, have by their mutual action acquired opposite electrical states, should be able to discharge these states one to the other, and yet remain in the same state they were in at the first, that is, entirely unchanged in every point by what has previously taken place; or, that the force which has enabled two particles by their mutual action to attain a certain state, should not be sufficient to make them keep that state. To admit such ef-

fects would be, he thinks, to deny that action and reaction are equal. The contact theory, according to him, assumes that a force which is able to overcome powerful resistance, both chemical and mechanical, can arise out of nothing: that, without any change in the acting matter, or the consumption of any other force, an electric current can be produced, which shall go on for ever against a constant resistance, or only be stopped, as in the voltaic trough, by the ruins which its exertion has heaped in its own course;—this, the author thinks, would be a creation of power, such as there is no example of in nature; and, as there is no difficulty in converting electrical into mechanical force through the agency of magnetism, it would, *if true*, supply us at once with a perpetual motion. Such a conclusion he considers as a strong and sufficient proof that the theory of contact is founded in error.

In a postscript, the author states that he has since found a passage in Dr. Roget's treatise on Galvanism, in the Library of Useful Knowledge, published in January 1829, in which the same argument respecting the unphilosophical nature of the contact-theory is strongly urged*.

* "Were any further reasoning necessary to overthrow it, (namely, the voltaic theory of contact) a forcible argument might be drawn from the following consideration. If there could exist a power, having the property ascribed to it by the hypothesis, namely, that of giving continual impulse to a fluid in one constant direction, without being exhausted by its own action, it would differ essentially from all the other known powers in nature. All the powers and sources of motion with the operation of which we are acquainted, when producing their peculiar effects, are expended in the same proportion as those effects are produced; and hence arises the impossibility of obtaining by their agency a perpetual effect, or, in other words, a perpetual motion. But the electro-motive force ascribed by Volta to the metals when in contact, is a force which, as long as a free course is allowed to the electricity it sets in motion, is never expended, and continues to be exerted with undiminished power, in the production of a never-ceasing effect. Against the truth of such a supposition the probabilities are all but infinite." § 113, p. 32.